nanoseconds are filled up with pulses. This situation will effectively jam all communications in a local geographic area. Furthermore, for the case of asynchronous UWB communications networks, the use of a sample-and-hold oscilloscope will not facilitate measurements of the emissions at all. This fact, perhaps more than any other, is why UWB communications devices must be far removed in frequency from the GPS bands or any other restricted bands.

Finally, UWB measurement testing is also complicated by the fact that the concept of bandwidth is ambiguous when applied to both continuous waves and UWB pulses. The term "bandwidth" can be used to mean "steady state, continuous bandwidth" or "instantaneous bandwidth". The latter is associated with receiver onset time, as well as the bandwidth of UWB individual pulses. Therefore, whereas with respect to the case of continuous, stationary interference, the steady state, continuous bandwidth of a victim receiver is adequate characterization for predicting electronic upset, it is not adequate characterization with respect to transient, nonstationary interference. In the case of the latter, characterization of victim receiver's onset time, and associated instantaneous bandwidth, are also required.

4. The Commission Should Not Eliminate Its Prohibition Against Class B, Damped Wave Emissions.

The Commission, noting very little objection in the comments on the *UWB NOI*, proposes to eliminate its prohibition against the use of Class B, damped wave emissions for UWB transmitters.[86] The Council appreciates that the Commission's rationale for such an action is based on the "low" power levels being proposed today for UWB transmissions – levels not quantified for sake of this particular discussion. The fact of the matter, however, is that there is no assurance that all future applications of UWB will employ similarly "low" power levels, nor is there any assurance that receivers associated with all UWB transmitters will render the prohibition irrelevant by

[86] *See NPRM*, FCC 00-163, slip op. at 26 (¶¶ 56-57) (citing 47 C.F.R. §§ 2.201(f) and 15.5(d)).

attempting to recover as much of the transmitted bandwidth as possible for information processing purposes.

For now, the Council believes it would be prudent to retain the prohibition until a regulatory environment can be established that ensures the stability of the NII.

E. The Commission Should Not Be Making Prejudgments About The Effective Date Of Rules That May Be Adopted In This Proceeding; It Should Await The Submittal Of A Basic Scientific Framework And Analysis Of Subsequent Test And Measurement Data.

1. The Commission Is Not Now In A Position To Be Adopting Broad Rules Of General Applicability.

As noted above, the Council recognizes that UWB proponents have made vigorous entreaties to the Commission and others in Government regarding the expeditious adoption of permanent rules that would permit the introduction of UWB technology into the marketplace. It is the Council's sincere hope that, as a result of comments filed in response to the *NPRM,* and the realization that UWB is not only an incompletely understood technology that was rejected because of its interference propensity, but one that poses unique technical and regulatory challenges, the Commission will reduce the frenetic pace of this proceeding and allow more of an opportunity for thorough reflection and consideration of test data.

At the very least, the Commission should recognize that it is premature for it to "propose to require that regulations proposed in this [*NPRM*] become effective 60 days from the date of publication of the Report and Order in this proceeding in the Federal Register."[87] There are no specific rule proposals included in the *NPRM*, only tentative conclusions, and this is not the type of proceeding where Commission rules developed for related services will provide a model for the rules to be adopted. To the contrary, the Commission will have to start largely from scratch – a

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87 *NPRM*, FCC 00-163, slip op. at 27 (¶ 59).

reality that elevates the importance of providing the public with an opportunity to consider and comment upon the specific rule provisions before they go into effect.

Finally, it now seems clear that the limited testing currently underway will not support the establishment of general rules that will apply to all prospective types of UWB devices and applications. Instead, the Commission may find itself in a position after all testing is complete, to identify the specific types of GPR and WID radar devices that may be licensed for operation, the frequency bands for such operation, and the precise regulatory conditions that would apply thereto. It may also be in a position to establish the cut-off point for the bands to be used by most or even all UWB devices at the 3.0 GHz level, and to impose the associated requirement that any UWB device or network operating above 3.0 GHz must strictly limit its unwanted emissions into the GPS L1, L2, and L5 bands to the levels to be determined by the Commission and NTIA. All other matters pertaining to UWB devices require more consideration and perhaps the establishment of the underlying science followed by completion of a more comprehensive round of tests and measurements.

2. The Commission Cannot Authorize UWB Devices Under Part 15 Of Its Rules, And Adoption Of Any Service Rules For Licensed UWB Operations Is Beyond The Current Scope Of This Proceeding.

As noted above,[88] and as indicated in the *NPRM*,[89] there is a fundamental distinction between authorizing unlicensed operation under Part 15 of the Commission's rules and establishing a service for which individual operators will be licensed. Given the wide range of possible deployments for some types of UWB devices, their broad impact across many spectrum bands, and the great difficulty of "putting the genie back in the bottle" once unlicensed devices have been dispersed throughout the NII, the Council is of the opinion that inclusion of UWB devices within Part 15 will

[88] *See supra* at Section II.E.

[89] *See NPRM,* FCC-00-163, slip op. at 8 (¶ 19).

not be a feasible option. As discussed above, the burden falls upon the proponents of this technology to make available devices during the experimental license process to demonstrate non-interference and thus potential eligibility for licensure.

Apart from statutory and administrative requirements, the principle of requiring intentional emitters to protect services that are already operating is a fundamental one, and simply represents sound public policy. Existing services have entrenched user communities that rely on the services they receive – especially those with safety-of-life functions such as GPS, and service operators not only provide jobs but also stimulate growth in other sectors of the economy.[90] Regulations that do not adequately assess the interference potential of UWB would pose a serious threat to the GPS industry, not only by allowing destructive interference, and thereby impairing public safety, but also by damaging investor confidence and impeding the development and marketing of new products.[91]

In any case, the Commission has clearly limited itself in this stage of the rulemaking to considering uses of UWB that are fully consistent with the fundamental non-interference policy underpinning Part 15. Not only is this docket denominated solely as a Part 15 proceeding, but the Commission also has stated in the initial *NPRM* that it is not proposing to allow specific types of UWB devices to operate on a licensed basis.[92] Accordingly, the Commission has appropriately

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90 As discussed above, GPS alone has an impact on the U.S. economy that cuts across virtually every sector, with aggregate revenues in the billions of dollars. *See supra* Section II.B.

91 Indeed, pursuant to the Congressional Review Act of 1996, any new agency regulation is deemed "major" if it is likely to result an annual effect on the economy of $100,000,000 or more, as determined by the Administrator of the Office of Information and Regulatory Affairs of the Office of Management and Budget. *See* 5 U.S.C. § 804(2). Any agency initiative deemed "major" is, in turn, subject to a special Congressional review process. *See* 5 U.S.C. § 801.

92 *See NPRM,* FCC 00-163, slip op. at 8 (¶ 19) ("We recognize that UWB technology may be developed for higher power applications such as wide-area mobile radio services. However, we find that such applications raise many new and novel questions, such as consistency with the international and domestic table of frequency allocations, and how such services might be licensed to share spectrum across broad frequency ranges used by multiple existing services and licensees. *We observe that there is insufficient information in the record to address such issues. Accordingly, we are not making any proposals at this time to allow high power UWB devices to operate under Part 15 or on a licensed basis.*") (emphasis added).

constrained the scope of the rule changes that might ultimately be adopted in an initial Report and Order to developing a new part.[93]

3. Any Rules Adopted In This Proceeding Would Be "Major Rules" And May Trigger Congressional Review Obligations Under The Contract With America Act of 1996.

The "Contract with America Advancement Act of 1996" (the "Act"),[94] an addition to the Administrative Procedures Act, imposes certain obligations on the Commission in connection with this proceeding that may prevent any rules adopted herein from taking effect at the end of the 60 day period following publication of such rules in the Federal Register. The Act provides for congressional review of agency rulemaking actions, and has particular significance in the case of rules concerning UWB devices.

Section 801 of the Act provides that before a rule can take effect, the promulgating agency (the Commission in this instance) must submit to the Senate and the House of Representatives a report containing a copy of the rule, its proposed effective date, and "a concise general statement relating to the rule, including whether it is a major rule[.]"[95] If a rule is a "major rule," the Act imposes a number of conditions on when the rule may take effect. For example, Section 801(a)(3) provides in part that:

> (3) A major rule relating to a report submitted under paragraph (1) shall take effect on the latest of –
>
> (A) the later of the date occurring 60 days after the date on which –
>
> (i) the Congress receives the report submitted under paragraph (1); or

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93 An NPRM must fairly apprise interested persons of the subject and issues before the agency to set forth a range of likely alternatives so that individuals may know whether their interests are "at stake." *See, e.g., Weyerhaeuser Company v. Costle,* 590 F.2d 1011, 1031 (D.C. Cir. 1978); *American Iron & Steel Institute v. EPA,* 568 F.2d 284, 291 (3d Cir. 1977).

94 *See* 5 U.S.C. §§ 801, et seq.

95 5 U.S.C. § 801(a)(1)(A).

(ii) the rule is published in the Federal Register, if so published;[96]

Additional time is provided for congressional review if the report concerning the rule is submitted to Congress within 60 days prior to the end of a congressional session.[97] Either of these triggers can delay the effective date of the rules adopted by an agency for a period substantially longer than the 60th day following Federal Register publication.

Under the Act, a rule is a "major rule" if the Administrator of the Office of Information and Regulatory Affairs of the Office of Management and Budget finds is likely to result in (A) an annual effect on the economy of $100,000,000 or more; (B) a major increases in costs for consumers, individual industries, government agencies, or geographic regions; or (C) "significant adverse effects on competition, employment, investment, productivity, innovation, …."[98] There is little question that, given the facts, reported above,[99] the presence of GPS alone makes the rules to be adopted in this proceeding "major rules" under the Act.

GPS has an impact on the U.S. economy that cuts across all economic sectors, with aggregate annual revenues in the billions of dollars. In 1999 alone, direct revenues attributable to GPS reached $2.07 billion.[100] Moreover, any disruption in or degradation to GPS will have significant adverse effects on competition and productivity.

As a result of the obligations imposed by the Act, it appears that the Commission may not be in a position to have rules developed in this proceeding go into effect on the 60th day following Federal Register publication, even if that were the desired result. This is just one more reason for

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96 5 U.S.C. § 801(a)(3)(A).

97 *See* 5 U.S.C. §§ 801(d) and 802.

98 5 U.S.C. § 804(2).

99 *See supra,* at Section II.B.

100 *See* Space Bus. News Article, at 4.

the Commission to proceed thoughtfully and cautiously as it addresses the issues surrounding implementation of UWB technology.

IV. CONCLUSION

The Commission's *NPRM* contains the proper emphasis on the importance of protecting GPS from harmful interference that may be produced into its frequency bands in the 1160-1610 MHz range by UWB transmission signals – i.e., the Commission expressly, correctly, and repeatedly emphasizes that the need to protect GPS, along with other safety services, is vital. In the foregoing Comments, the Council has taken a thorough and contemplative look at the Commission's proposals regarding the establishment of a regulatory regime for applications employing UWB technology, and has come away with the unmistakable conclusion that the Commission should use the opportunity of this initial rulemaking effort to devote itself to gaining an understanding of the physical science associated with operations that take place in the time domain before it attempts to pigeonhole the time domain aspects of UWB into the longstanding frequency domain regime that has been the foundation of the Commission's structure since its inception. Notwithstanding the magnitude of the challenges facing the Commission, the Council is prepared, conditionally, to endorse the establishment of rules that would permit the introduction of UWB technology in ground-penetrating radars and wall-imaging devices in a non-overlapping portion of the frequency spectrum above 2.9 GHz, subject to the codification of the several specific safeguarding conditions provided by the Council that are all essential to ensuring the protection of GPS and its users.

At this time, and due to the limited state of understanding of UWB technology – with its infinite array of waveform variations, and the technical, geographic, and operational limitations that are associated therewith – the Commission is not in a position to adopt general enabling provisions for UWB technology. Instead, any rules adopted by the Commission in this and the necessary follow-on proceedings must specifically delineate the types of UWB devices and services that have been proven by the proponents thereof to be compatible with existing radio services, state the specific conditions under which they may operate (including limitations on unwanted emissions and identification of the means by which compliance with those limitations will be ensured), and expressly forbid all other uses of UWB technology until such time as a demonstration of compatibility with existing radio services is provided and accepted.

The Council has actively participated in the development of the various testing and measurement programs now under way to determine the impact of UWB transmissions on GPS, and looks forward to having the opportunity to provide comments and analysis both on the initial testing results that are presently due to the Commission next month, and on the inevitable follow-up studies that will build upon these preliminary results and address the numerous and substantial unaddressed questions about such critical topics as the potentially severe impact of networked UWB emitters.

By following the cautious, rational, and constructive approach detailed by the Council in the foregoing Comments, the Commission can both satisfy its obligation to ensure the protection of all uses of GPS, and facilitate the introduction of a new and technically compatible class of radios employing UWB technology to the public.

Respectfully submitted,

THE U.S. GPS INDUSTRY COUNCIL

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ATTACHMENT A

TECHNICAL APPENDIX

Differences in Time Domain and Frequency Domain Analysis

The NPRM reveals the common belief that the analysis methods used for characterizing continuous wave communications are appropriate for characterizing the damped transient signals of UWB technology. These methods developed for frequency domain analysis, are not appropriate for analysis of UWB signals operating in the time domain. For example, while both continuous wave and UWB signals *can* be analyzed with Fourier methods, only in the case of continuous waves are such methods appropriate for making explicit the nature of such signals. In the case of UWB signals, the more general Laplace analysis is required, which explicitly characterizes both the harmonic nature of the continuous wave and the UWB signal, and, more importantly, also the damped nature of the UWB signal.

A Laplace characterization of UWB signals is obtained with a real-time, time-domain, sample-and-hold oscilloscope, sampling the UWB signals at Nyquist-sampling rates. Having captured the signal and/or the signal train by this method, the captured signal/train can then be readily Laplace analyzed off-line. Signal amplitude is also measured by this test method.

The NPRM reveals an awareness that:

- state-of-the-art spectral analyzers are too slow to provide a valid characterization of UWB signal amplitude,

- that a power density spectral analysis is likewise inadequate,

- that the use of sample-and-hold time domain oscilloscope signal capture methods is more appropriate.

Characterizing the interference of multiple UWB signal train transmitters, operating asynchronously in complex mixing permutations, also needs to be addressed in a comprehensive test and analysis program.

Operational link analysis addressing UWB interference needs to include specific UWB interference test conditions, including testing the amplitude of UWB interference by time domain sample-and-hold oscilloscope operating at Nyquist-frequency rates. Since different UWB signals will create different noise conditions, each single signal should be characterized. Consequently, a generic "one size fits all" UWB interference test result will not cover the many types of UWB signals. The many types of possible UWB signals and pulse repetition rates will create different types of 1/f (non-Gaussian) noise, each of which will have different interference properties. The complexity of this analysis is compounded by the extent of the nonlinearity of a receiver's front-end as a unique function of a particular receiver.

Many Meanings of The Term "Ultrawideband"

Ultrawideband, or UWB signal, has come to signify a number of synonymous terms, including: carrier-free, baseband, time domain, nonsinusoidal, orthogonal function and large-relative bandwidth radio/radar signal.

The term UWB can be misleading because it makes no reference to the temporal shortness of the pulse. If only bandwidth was necessary to classify a pulse as UWB, then a chirped signal covering an ultrawide bandwidth, but delivering that bandwidth over a one second period, would also qualify. The term UWB does not convey the notion that the signal intended to be referenced by the term, is not only:

(1) ultrawideband; but also

(2) delivers that bandwidth in an ultrashort period of time; and therefore

(3) the temporal duration of the pulse or signal is ultrashort.

Usually, the temporal duration of the UWB signal is a few nanoseconds.

All Signals Transmitted Through An Antenna or Waveguide Have a Fundamental Emission

The notion that UWB signals have no center or average frequency or fundamental emission or fundamental lobe or "carrier", f_0, is incorrect. There are no electromagnetic emissions that are not harmonic emissions. Neither a step function nor the mathematical term – "distribution function" – e.g., a Dirac function, can be transmitted. Any pulse to be transmitted must pass through an antenna, which differentiates the driving pulse. Therefore a transmitted short pulse will at best be a monocycle – that is, a monocycle of what is a center or average frequency or "carrier" – or, more typically, a damped oscillation, with a damping in both the risetime and the fall time.

The fundamental emission identified in the NPRM (NPRM, p. 3) is the main lobe when viewed on a spectrum analyzer with the sidelobes not considered, or 2/tau, where tau is the pulse temporal length. The fundamental emission can be the resonant frequency of the transmitting antenna used which determines the center frequency of the radiated pulse (NPRM, p. 2). However, a spectrum analyzer cannot adequately determine the main lobe, and therefore the definition of a UWB signal cannot be stated in terms of either the resonant frequency or the pulse temporal duration alone. The fundamental emission should be determined by:

> (1) a fast sample-and-hold oscilloscope, which can determine the temporal duration and phase, and
>
> (2) the oscilloscope output utilized to calculate the real and imaginary Laplace transform of the signal.

By this procedure, the signal's oscillatory component and damping component can be obtained. A spectrum analyzer, provides no information concerning timing, or when the particular frequency components in the signal occurred in time. Furthermore, the fastest spectrum analyzers are insufficiently fast in sampling time to provide an accurate measurement of signal amplitude.

At What Bandwidth Does a Signal Become Ultrawideband?

One suggestion to define the signal's bandwidth is to use the equation B = 6.36/tau, where B is the bandwidth in MHz, and tau is the emitted pulse duration in microseconds at the 50% amplitude (voltage) points. (Annex J of Chapter 5 of the *National Telecommunications and Information Administration's Manual of Regulations and Procedures for Federal Frequency Management*, quoted in NPRM, p. 2, footnote 8). However, it must be recognized that this proposed definition is arbitrary, and does not address whether the bandwidth is

(a) instantaneous over tau, or

(b) uniformly sequential (i.e., chirped) over tau, or

(c) arbitrarily modulated in time over tau.

There will be differences in the potential for interference between (a), (b) and (c).

All UWB Signals Are Not The Same

A UWB signal is a monocycle of average frequency f = 1/t, where t is the temporal length of the signal and of risetime tau. In operation, a UWB signal is rarely that cleanly defined and has more or less "ringing" depending on the antenna, the antenna coupling, and the antenna driver. Therefore, there is no generic UWB signal. This fact is key when testing UWB signal interference capabilities. If x different UWB signals are chosen for testing, then only x conclusions can be drawn from the test data.

Developing a Comprehensive Interference Test Program

There are two major ways that a UWB signal can cause interference:

(1) the center or average frequency of the individual signal is in-band to the victim receiver; and

(2) the repetition frequency of the signal train is in-band to the victim receiver.

A comprehensive test plan would need apply the following:

(1) a variety of UWB signal pulse repetition frequencies (PRFs);

(2) a variety of permutations of interpulse intervals between UWB signals in a pulse train; and

(3) a greater variety of interpulse intervals between UWB signals from different pulse trains arriving at the same receiver.

The plan would also need to take account of the fact that the variety of interpulse intervals increases further, as a function of the number of asynchronous UWB transmitters.

The total number of combinations is the product of: #1 x #2 x #3 x #4 types of different pulse trains arriving at the GPS receiver for the total types of UWB signals. The arithmetic provides a prohibitively large number. Therefore a comprehensive test plan would involve use of a white noise analysis of victim receivers.

Spectrum Analyzers – Can They Sample at the Nyquist Rate?

Assume the highest sampling bandwidth of today's spectrum analyzers: 30 MHz. The sampling time is then 333 nsec. Assume a 1 nanosec pulse of perhaps 4 GHz bandwidth, then such a spectrum analyzer will sample that 4 GHz signal at every 30 MHz interval, and "remember" the result of each sample, until the full 4 GHz is sampled. Moreover, this 1 nanosec pulse will be sampled not in one single attempt, but repetitively, for each of these 30 MHz subbands and each over 333 nsecs in turn. Consequently, the measured amplitude at each 30 MHz band is an average of the 1 nanosecond over the 333 nanoseconds, and this reasoning leaves aside the damping effect of the resistor-capacitor (RC) time constants of the analyzer. This state-of-the-art spectrum analyzer (and power density spectrum measure) will be at least 333 times less than a true time domain and peak power measure. Such spectrum analyzers cannot sample at the Nyquist rate in the case of UWB signals.

A Single UWB Signal Train Has Many Power Density Spectra and Many Autocorrelations

The power spectrum or the power density spectrum, both of which are based on harmonic analysis, do not apply to signal or signal train events sampled *below* the Nyquist sampling rate for the highest frequency in those events. A very short duration pulse of low energy creates fields of high electric field strength (*V/m*) and power (*V.I*). With energy *(J)* constant, still greater field strengths and powers can be created by further shortening of the temporal length of the pulse.

The FCC has correctly questioned reliance on the power spectral density as the appropriate measure for UWB emissions (cf. NPRM, p. 15, para 34), yet, paradoxically has proposed (ibid, p. 18, para 15) that for UWB emissions > 2 GHz, limits still be based on power spectral density measurements (signal energy level per unit bandwidth).

The existence of many power density spectra and many autocorrelations is clearly represented in an *ambiguity function,* which combines the power density spectra associated with a single signal or signal train at a variety of frequency interval sampling rates with the autocorrelations at a variety of temporal interval sampling rates. The ambiguity function *always* has a central peak or spike representative of the individual pulse signal. However, that central peak is only discerned if the Nyquist frequency/temporal sampling interval is available to the test instrument. As indicated above, it is not available in the case of the spectrum analyzer.

Victim Receiver Nonlinearities

Comprehensive testing of the interference capabilities of UWB signals and signal trains must take into account that victim receivers will have an amplitude-dependent nonlinearity or temporal summation of pulses with short interpulse intervals due to the damped response of such receivers.

Typical Receiver Response To Interfering Continuous Signals May Not be Extrapolated to Interfering Damped Transient Signals – i.e., UWB.

The assumed absence of interference of UWB communications systems with other conventional receivers and also electronic upset of a variety of forms of electronic equipment has yet to be adequately validated. There is also an assumption that pulse signals above 2 GHz are relatively noninterfering due to propagation losses. (NPRM, p. 13, para 27). Indeed, the effect of transient RF signals, as opposed to steady state signals, on materials and circuits, is a complex subject not commonly understood. (See Barrett, T.W., Energy Transfer

& Propagation and the Dielectrics of Materials: Transient versus Steady State Effects. Ultra-Wideband Radar: Proceedings of the First Los Alamos Symposium, 1990, B. Noel (ed) CRC Press, 1991; Barrett, T.W., Energy Transfer through Media and Sensing of the Media, pp. 365-434 in Introduction to Ultrawideband Radar Systems, J. D. Taylor (Ed), CRC Press, Boca Raton, Florida, 1995). Moreover, the effect of a train of transient signals (UWB) on conventional receivers and forms of electronic equipment may be a nonlinear temporal summation of the individual transients and a function of the relaxation time of a particular material or a particular circuit. (In the case of a circuit, this relaxation is determined by the lumped resistor-inductor-capacitor (RLC) components.) Making the problem of interference complex to study is the fact that although there is a short list of electronic materials, there is a long list of possible electronic circuits in victim receivers, each with a specific relaxation time.

Regarding possible variables affecting susceptibility to interference, the FCC mentions: "typical front-end bandwidths before the first mixer in receivers; typical dynamic range limits of receiver mixers; typical IF bandwidths; and required signal-to-interference ratios for reliable performance of the system assuming interference is white gaussian noise...." (NPRM, p. 14, para 33), These variables are, indeed, important. However, typical performance refers to continuous, rather than transient, signals. Furthermore, a pulse transient is a broad spectral bandwidth signal (mathematically), but the frequencies are precisely phase-locked, not randomly phase related as in white noise. Therefore it is not clear that these typical measurements will provide an accurate prediction of interference by real transient signals.

Shannon's Channel Capacity Laws Apply To UWB

Shannon's channel capacity laws are universally valid and apply to UWB communications systems. UWB communications systems have yet to be evaluated with respect to

(a) bandwidth efficiency; and

(b) power efficiency.

UWB communications systems' bandwidth efficiency rating – the measure of bandwidth (i.e., real bandwidth, not merely that bandwidth which can be detected above conventional receiver thresholds) used for data rate achieved – is presently extremely poor, and its power efficiency rating – i.e., the distance achieved for power (peak not average) used – is also poor.

UWB Does Not Provide A Vehicle for More Efficient Use of the Spectrum

In declaring its interest in considering permitting the operation of UWB systems, the FCC stated that UWB "would permit scarce spectrum resources to be used more efficiently." (NPRM, p. 1). The goal to achieve spectrum efficiency also needs to address the issue of whether or not UWB transmissions interfere with the reception of conventional frequency receivers, i.e., whether the noise floor of such receivers can be utilized without penalty. This is a different efficiency goal than achieving the highest data throughput through a channel of precisely defined and restricted bandwidth. Engineering trades offs of time, bandwidth and power assume a zero-sum game. Attempting to mediate these zero-sum aspects by asserting that the *S/N* penalties from "reuse" of spectral areas already occupied by conventional narrow and broadband systems are spread over *many* victim receivers. Consequently, the *penalty per victim receiver* is small, and represents an exercise in interference tolerance rather than spectrum efficiency. But "tolerance" is not "efficiency." An analogy is if someone were seeking permission to appropriate only $5 from each of a large number of persons, justifying this act an efficient reuse of money. The fact that appropriating $5 from a victim may not exceed that victim's indignation level cannot be used to extrapolate to the victim's response when multiple or aggregate appropriation occurs. With UWB, companies already inhabiting spectral areas are being required to tolerate additional interference without seeing any commensurate gain either in individual or overall efficiency.

Nyquist Sampling Laws Apply To UWB

The measurement of peak power levels is as accurate as the sampling rate of the measuring device. Since the sampling rate is a measure of operations over time, in assessing the peak power of a UWB transmitter, it is necessary to focus on signal duration and its risetime. If the reciprocal of the signal duration and risetime are greater than half the sampling rate of the measuring instrument (i.e., greater than the Nyquist rate), the measured power is not a true peak power measure. The NPRM seeks clarification that peak output is not the crucial variable in causing interference to a narrowband receiver, and that only the power spectral density of the pulse and the pulse repetition frequency are causes of that interference (NPRM, p. 19, para 41). The NPRM has proposed two methods of measuring peak power:

(1) the peak level of the emission over a bandwidth of 50 MHz, and

(2) the absolute peak output of the emission over its entire bandwidth (*ibid*, pp. 19-20, para 42).

Both proposals do not address the question of how "peak power" is to be measured. The "peak power" in a 1 GHz monocycle signal, measured by an instrument with a sampling rate of less than 2 GHz, is actually an average power regardless of the emission bandwidth – instantaneous or sequential – sampled. In attempting to define an appropriate measuring instrument, a degree of support has been expressed for a "pulse desensitization factor" correction of an inadequate sampling spectrum analyzer (NPRM, p. 23, para 51, footnote 107), a method that guesses at a true measure on the basis of a measurement at an inadequate sampling rate. (*Ibid*, p. 24, para 51). This method is not adequate. The appropriate Nyquist- sampling oscilloscope is an adequate measuring instrument (*ibid*, p. 53, para 24).

The fastest spectrum analyzer of today has a maximum sampling bandwidth of 30 MHz (e.g., Tektronix FSEB series). The more common sampling bandwidth is 10 MHz. Therefore, in order to measure a monocycle-pulse with a bandwidth of, e.g., 4 GHz, it is necessary to transmit the monocycle multiple times. Due to the hold capability of the spectrum analyzer, which attends to the monocycle in, e.g., 10 MHz, bandwidth increments, it is possible to obtain a representation of the total bandwidth of the monocycle. However, only if the spectrum analyzer has I and Q analysis capability (signal vector analyzer) is there any measure of phase. This means that knowledge of <u>when</u> the frequency components in the total bandwidth occur is not available from a spectrum analyzer, and this knowledge has relevance to a valid measurement of the peak power.

The usual method of choice for measuring peak power and the damping characteristics of a short waveform is a sample-and-hold oscilloscope. For example, a Tektronix 694C is capable of 10 gigasamples/sec and the Tektronix 7404 is capable of 20 gigasamples/sec. Using these time domain sampling oscilloscopes, insight can be obtained into the peak power levels of the monocycle, as well as both the harmonic and damping characteristics.

Power Spectral Density Measures Are Inappropriate in Measuring the Power in UWB Signals

In the case of continuous wave systems, standards of emission have relied on power spectral density measurements. However, it is well known that the power spectral density measure, with origins in harmonic analysis, and with a relationship to the autocorrelation function, is an entirely inappropriate measure of transient, and UWB, signals. The power spectral density is an even function of frequency and possesses no phase information about the signal. A transient signal is not an even function of frequency and a valid peak power measurement is critically dependent on signal phase. Identifying a low power spectral density as an indication of negligible interference potential with respect to narrowband receivers is incorrect since, in fact, such a harmonic analysis is an inappropriate continuous wave (harmonic) analysis for a UWB signal transient In fact, a transient of rapid change in field strength could have a broad and flat power density spectrum, but yet have powerful interference, and even electronic upset, capabilities. Consider:

(a) 1 Joule of energy delivered continuously and evenly over one second is 1 Watt of power;

(b) the same 1 Joule of energy delivered discontinuously over 1 nanosecond is 1 GigaWatt of power; but

(c) the same 1 Joule of energy delivered discontinuously over 1 nanosecond and measured at a 1 sample per second sampling rate is 1 Watt of power.

A fast risetime pulse not only can produce multiple harmonic responses in a narrowband receiver, but even considerable destructive heating effects.

A UWB Communications System Is Not a Spread Spectrum System

In comparing a UWB system with a spread spectrum direct sequencing system (DSSS), it might be supposed that there is an exact comparison between the UWB bandwidth produced by the shortness of the pulse duration and the DSSS bandwidth produced by spreading from a chipping sequence. However, this comparison is misleading. Whereas in the case of UWB *all the energy* across the bandwidth constitutes the signal, in the case of DSSS *only* that energy within the spread bandwidth present *before spreading and before transmission* constitutes the signal. The remainder of the energy in the spread bandwidth after reception is rejected as noise. The difference between the two approaches is indicated by the fact that shortening a UWB pulse must be compensated by an increase in the peak power to preserve the energy per bit, but the energy per bit is independent of the chip rate and dependent on the data rate in the case of DSSS.

It might also be supposed that a UWB communications system has an advantage over a DSSS system in that UWB can utilize coherent addition of *N* pulses to achieve a bit signal-to-noise which is *N* times the *S/N* of an equivalent DSSS system. However, the DSSS equivalent of UWB coherent addition is processing gain not bit *S/N*. Furthermore, just as a DSSS system trades the bandwidth available for data transfer and thus data rate, for processing gain and *S/N*, so UWB trades data rate for coherent addition and *S/N*. Rather than supplying an advantage, UWB coherent addition is merely a strategy for maximizing *S/N* in the presence of noise in the channel, just as processing gain is such a strategy for DSSS to maximize *S/N*. In both instances, if all else remains constant, the increase in *S/N* is achieved at a price: a decrease in the data rate. If the data rate remains constant, there are other penalties for the adoption of these strategies. Just as there is minimal processing gain for a high data rate DSSS system, so there is minimal coherent addition for a high data rate UWB system. Both approaches must then increase the average power, and in the case of a UWB system, the peak and average power will eventually equalize.

A possible choice for a UWB system is to increase the pulse repetition rate to maintain a set data rate, but just as in the case of a DSSS system in which the chip rate is increased, the penalty for this choice is an increase in system complexity, as well as average power. There is a direct correspondence between the number of pulses per data bit in a UWB system using coherent addition and the number of chips per data bit in a DSSS system. It is also important to recognize that these penalties are a consequence of figures of merit which address *peak* power. Confusion arises when comparisons are switched between *peak* and *average* powers of different communications systems and the corresponding figures-of-merit are changed at will.

UWB Communications Systems Cannot Operate Below the Noise Floor and Achieve Commercial Utility

The front-end of a UWB communications system is necessarily broadband and that receiver front-end receives UWB signals supposedly below the threshold of conventional receivers. To achieve this below-the-noise-floor performance requires a penalty – the lowering of the S/N of the UWB receiver. An attempt to compensate for this penalty is made by stating that each bit of transmitted information is encoded into a dithered code in one-to-many mapping. (One bit of information is encoded over many UWB dithered pulses which are asynchronous with synchronous transmitters). But one-to-many mapping has another penalty – a reduction in the channel capacity or data rate. The sum of these penalties increases the UWB communication receivers' vulnerability to interference from conventional transmitters. The potential commercial utility of UWB communications systems will require higher data rates which will lead to higher transmit power. Higher UWB transmit power will lead to greater levels of interference to conventional receivers. Consequently, the overlay of time domain pulse communications over frequency domain systems is a zero-sum tradeoff.

ATTACHMENT B

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS SPACE AND MISSILE SYSTEMS CENTER (AFMC)
LOS ANGELES, CA

23 May 00

MEMORANDUM FOR UNIVERSITY OF TEXAS (UT) APPLIED RESEARCH LAB (ARL)

FROM: SMC/CZE
2435 Vela Way, Suite 1613
El Segundo, CA 90245

SUBJECT: GPS JPO Comments to the Time Domain/UT ARL UWB Test Plan

1. The Global Positioning System Joint Program Office (GPS JPO) has reviewed the 5 May 2000 draft Ultra Wideband (UWB) test plan produced by the Applied Research Laboratory at the University of Texas (ARL/UT). The attached report compiled by our Aerospace technical staff details the findings.

2. As mentioned in the draft, the test plan does not intend to address the issue of the Notice of Preliminary Rule Making (NPRM) released by the FCC to amend the Part 15 rule to allow UWB devices in the GPS bands. In general, the findings based on a limited number of emitters using a particular technology cannot be used as the basis for sharing between GPS and a very loosely defined class of radio frequency transmitters. A more comprehensive test such as that planned by the Department of Transportation is better suited to address the broader NPRM issues. Nevertheless, we provide the attached comments to help tailor the test plan towards the safe development of UWB devices and protection of GPS services.

3. Please be advised that the GPS JPO interaction with Time Domain does not constitute an endorsement by the GPS JPO, the US Air Force or the Department of Defense of Time Domain's product/technology. Neither does it constitute agreement or acknowledgement that it is suitable for its intended purpose or any particular purpose, or that it is operable without Radio Frequency (RF) Spectrum interference.

4. If you have any questions, please contact Lt Muhammad Khan at 310-363-6373 or email at muhammad.khan@losangeles.af.mil. Thank you.

//Signed//
WILLIAM K. KANESHIRO, Lt Col, USAF
Chief, GPS Systems Integration and Engineering
NAVSTAR GPS Joint Program Office

Attachment:
Comments to Test Plan

Review of the Test Plan for UWB/GPS Compatibility Effects for Ultra Wideband Testing Consortium Time Domain, Huntsville Alabama Dated May 5, 2000

Steven Lazar, Clyde Edgar, Kristine Maine, Mark Simpson, Robert Wong, Srini Raghavan
The Aerospace Corporation
May 18, 2000

Executive Summary

The review of the test plan has found that it is not intended for, nor adequate to, provide answers to the questions posed by the Notice of Preliminary Rule Making (NPRM). The NPRM is a proposal to amend the Part 15 (unlicensed emitter) rule that includes the bands utilized by GPS to permit Ultra Wideband devices. The equipment used, test conditions, and data types collected are <u>inadequate for determining the safe distance</u> between the specific emitters and the representative GPS equipment tested. Neither the conclusions of this test nor any results from the data can properly address the potential for interference from this class of devices into a band that is currently used for safety-of-life operations for the general public in numerous and rapidly expanding applications.

Introduction

The Aerospace Corporation has reviewed the Test Plan for UWB/GPS Compatibility Effects for Ultra Wideband Testing Consortium Time Domain Corporation, Huntsville Alabama, Dated May 5, 2000 written by the Applied Research Laboratories at The University of Texas at Austin. The comments to the test plan are found below. In addition to the test plan, Aerospace has participated on three occasions in meetings with Time Domain Inc. and/or University of Texas personnel at the JPO. They have stated that this test will address the concerns over the Notice of Preliminary Rule Making (NPRM) released by the FCC (May 11, 2000) proposing to amend Part 15 rules to allow Ultra Wideband devices to radiate in bands that include the GPS frequencies. The commission has allowed for comments on the NPRM until October 30, 2000. This review of the test plan does not address:

1) the feasibility of sharing between UWB and radionavigation systems in L-band,
2) the adequacy of the NPRM for protecting GPS,
3) whether this test should be conducted or not, or
4) the risk inherent in trying to resolve this issue within an approximately five month time frame.

This review is intended to determine if the test plan can meet its stated purpose, whether the type, means and equipment used to collect the data are adequate and sufficient to make a finding that there are safe separation distances between GPS and UWB.

Intention of the Test

In the introduction of the test plan, Applied Research Laboratory of the University of Texas at Austin (ARL:UT) has presented its formidable credentials for conducting GPS tests. These tests have contributed to the performance of GPS in certain applications. While the fidelity of tests conducted to determine GPS performance are without question, these types of activities are not indicative of the facilities capabilities to determine electromagnetic compatibility. The latter is a specialized field that requires unique test equipment and expertise, and is traditionally conducted at testing facilities that have been certified to meet designated national or international standards. The lack of these elements will be pointed out later in this report. Furthermore, the introduction to the ARL:UT test plan admits that the usefulness of the results is limited. "...Neither is it the purpose of this test plan to attempt to represent the qualitative impacts of the FCC's NPRM to GPS receivers." The plan goes on propose an analysis method as a "... limited justification of why the specific data types are collected." In not fully addressing the analysis, the type of data and collection means are inadequate to properly address the NPRM. This will be shown in specific comments on the body of the test plan.

Alternatively, the objective of the raw data collection is given as "...to determine a representative minimum safe distance between ...UWB...and GPS receivers...such that the GPS receivers experience no harmful interference." The use of terms relating to safety and harmful interference implies that certain standard test procedures will be performed. This is not the case. For instance, for the FAA safety is defined via RTCA DO-160, which determines whether emissions are excessive and whether a unit is susceptible (in addition to full aircraft flight-testing.) In addition, the ITU has very stringent standards on allowable emissions of intentional transmission devices both in and out of band. The European Union (ISO, EEC, IEC, CISPR, etc.) has standards in electrical safety to determine whether a product is safe or not. Also there is a US legal standard of meeting all applicable standards plus preventing known harm or harm that you should have known of in addition for being responsible for an actual damage caused. None of these standards or accepted practices is used in this test plan. An additional point to consider is the certification of the test facility. There is no mention of safety accreditation of the ARL:UT laboratory that would be recognized by the safety community. This may be a necessary requirement for reliable tests.

Test Description

The test plan calls for collecting the spectral content in 2 MHz and 20 MHz bands around L1 and L2 (Section 1.7). The frequency range of the emissions testing should be extended to be 9 kHz to 10 GHz for at least one test (see also Table 3-1.) The bandwidths used to measure the emissions centered on L1 and L2 should be 2, 20, 40, 60, 80, and 100 MHz to account for the difference in GPS receivers. (The bandwidths called out in the plan are relevant to the GPS signals but have no bearing on either the bandwidth of the receiver front-end, IF etc... or the signal emitted by the UWB device.) Considering the plans to modernize GPS, L5 should be included as well.

The use of GPS simulators with a 'normal' 24-satellite GPS constellation (Section 3.1, 4.1.1 and later in the plan) does not address the specific user location and time-of-day simulated. The plan does not include any details regarding the co-channel- (or self-) interference of the GPS C/A-codes which is present and to which the UWB emission is added. The co-channel interference results are used in sharing studies at the ITU, in coordination of foreign satellite systems and other analyses of GPS interference; they should be used here too.

A spectrum analyzer is identified for measurement of UWB sources (Section 3.1.1.) That this test instrument is inadequate to fully characterize the UWB emissions is stressed in the NPRM under measurement procedures (Paragraphs 50-53). A fast sampling oscilloscope should be used as well, with evidence provided that the appropriate measurement technique for capturing the peak power is used. Parasitic interactions are quite common at these frequencies and comparing both time and frequency data representations will instill confidence in the test measurement scheme.

In Table 3-1, the spectrum analyzer settings are listed. The measurement bandwidths, sweep rates, dwell times, and step sizes, etc., for at least one measurement should be chosen from MIL-STD-462D and ANSI 63.2-1987 (FCC emissions measuring technique). This is important because the amplitude of the signal recorded is dependent on the measurement bandwidth.

The GPS test receivers used do not include any military receivers (Section 3.1.4.) The DoD user segment should not be disregarded. Equipment that use the P(Y)-code have wide front-end filters, are built to operate under conditions of high dynamics and integration with other systems. They should not be left out of the test (provisions may be made for the collection of US Government classified data if necessary.) A representative WAAS receiver would also be a useful test addition since it will probably become a widely used service in the future.

In Table 3-2, only the pulse on/off times are used as a test variable. The test should investigate the effect of different code modulations on the emission, since there may be interactions with the GPS receiver signal and operating modes. It is also possible that UWB devices will be used for variable data-rate communication, so that different modulation types is essential for this type of test.

The UWB transmitter antenna will be placed one meter above the GPS receiver antenna (3.2.1.) From the test plan, it cannot be determined if the antennas are in the near field or not. Furthermore, the antennas in this configuration may not demonstrate the worst-case scenario. Instead of antenna gain and pattern, antenna factors (standard for ECM testing) might be more appropriate. Another way in which the signal may interfere with a GPS receiver is by leakage through the chassis. Tests should also be conducted with a shielded chassis to verify that only the signal coupling into the antenna is significant. Otherwise, the orientation of the GPS receiver may be a factor in the measurement results.

In Section 3.2.3.1, the plan states that "...emissions from the GPR will need to be measured in a way that accurately reflects the amount of energy that is actually directed at the GPS receiver, since this energy is reflected and leaked out of the ground." This characterization does not allow for accidental misuse of the device wherein it may be pointed directly at a victim GPS receiver, and the direct line-of-sight emission rather than scattered or reflected emission would be the data to be measured. In the NPRM (Paragraph 25) considers that "...a switch or other mechanism to ensure that operation occurs only when it is activated by an operator and the unit is aimed directly down at the ground." If such safety devices are to be mandatory for Part 15 waiver, then tests of the efficacy of the switch should be included in the test plan.

The aggregate test is planned to have the UWB emitters in a ring around the GPS receiver (Figure 3-15). This may not be the worst-case scenario. If a circular pattern is used, a recommended modification is that the UWB be elevated with respect to the GPS antenna so that the emission into the receiver is at a higher elevation angle.

In Section 4.1, the statement is made that four separate tests will be performed, yet only three tests are described in the text.

Section 4.1.1 details the conducted test. The UWB antenna determines characteristics of the signal; in the conducted tests the antenna and therefore the bandpass characteristics of the signal are different from the radiated tests. This difference is not accounted for in the test plan.

In the conducted tests, using the GPS constellation simulator, the noise background (typically due to sky temperature and the low-noise-amplifier noise figure) should be added to the GPS test set to establish a noise floor. This is a good practice; otherwise the simulator power and the noise figure into the receiver (which is usually unknown) establish the carrier-to-noise-density ratio (C/No). Once the baseline noise background is established, the added noise and the effect on the receiver can be accurately characterized. A calibrated, broadband noise source is necessary for this purpose.

There is virtually no information in the test plan on the GPS scenarios tested. What are probably not included are tests in which user dynamics (moving receiver) are included. Velocity and acceleration of the receiver introduce stress to the tracking-loop, which may have bearing on how the receiver reacts to interference. Aviation scenarios, using maneuvers expected in various flight operations, should be tested for impact to civil use of GPS. Other dynamic scenarios to accurately test military applications may be necessary as well.

Summary

The test plan has been reviewed and specific comments to improve the test have been made. In the present form, the test does not allow for a determination of the safe distance between the devices tested. Even a properly conducted test, however, cannot be used for making a determination regarding UWB as a whole.